GEOLOGICA BELGICA (2011) 14/3-4: 289-292

SHORT NOTE

THE TECTONIC EVOLUTION OF THE CHUYA-KURAI ZONE (SIBERIAN ALTAI MOUNTAINS) BY MEANS OF MULTI-METHOD CHRONOLOGY

Willem VANDOORNE, Johan DE GRAVE, Stijn GLORIE & Peter VAN DEN HAUTE

(3 figures)

Geochronology Groep, Department of Minerology & Petrology, Ghent University, Ghent, Belgium.
E-mail: Willem.Vandoorne@Ugent.be

ABSTRACT. The Phanerozoic tectonic evolution of the Chuya-Kurai zone was studied by means of zircon U/Pb-dating, apatite fission track (AFT) and apatite (U-Th)/He (AHe) thermochronology performed on basement rocks. Our results suggest that multiple magmatic episodes during the Paleozoic, related to the accretion-collision tectonics in Central Asia, affected our study area. Mesozoic and Cenozoic basement cooling events are interpreted as periods of tectonic reactivation. A new tectonic model for Late Cenozoic evolution of the Chuya-Kurai zone is proposed.

KEYWORDS: Central Asian Orogenic Belt, geochronology, thermal history, intracontinental reactivation, tectonic denudation

The Central Asian Orogenic Belt (CAOB) is the world's largest and most active intracontinental deformation belt. It stretches from the Pamirs and the Tibetan Plateau in the SW to the Stavanoy Range in the NE (Dobretsov et al., 1996). The Altai Mountains occupy a central position within the CAOB, in the border region of Kazakhstan, China, Mongolia and Russia (Fig. 1). The Altai are characterized by highly alpine mountain ranges with

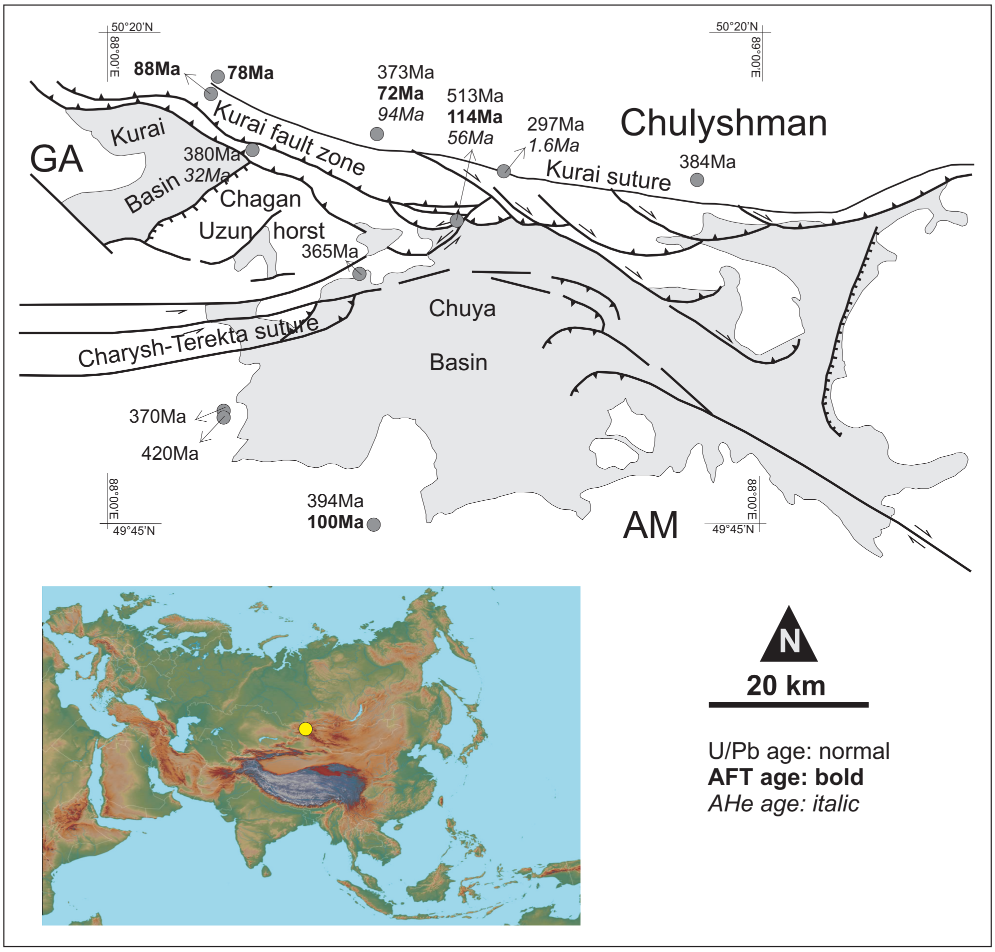

Figure 1. Schematic structural map of the Chuya-Kurai zone (CKZ) with indication of U/Pb ages (normal text), AFT ages (bold) and AHe ages (italic). GA = Gorny Altai; AM = Altai-Mongolia. Shaded areas represent Cenozoic sedimentary basin infill. Inset: general location of the Altai Mountains. Discussion: see text.

summits up to over 4000m, separated by intramontane basins of which the present Chuya and Kurai basins are examples.

In the Altai region, the CAOB consists of a complex patchwork of tectonic terranes accreted to the Siberian continent during the Paleozoic as a result of the progressive closure of the Paleo-Asian Ocean (PAO) (Windley et al., 2007). These terranes are bound by suture zones. In the Chuya-Kurai zone, two suture zones, the Kurai suture and the Charysh-Terekta suture, delimit three tectonic terranes: Gorny Altai, Altai-Mongolia and Chulyshman (Fig. 1) (Buslov et al., 2001). Gorny Altai consists of an island arc system, paleo-seamounts and carbonate platforms, all accreted to the Siberian continent during the Early Cambrian (Buslov & Watanabe, 1996; Safonova et al., 2008). Altai-Mongolia and Chulyshman represent peri-Gondwanan fragments initially located in the PAO, where they mutually collided during the Middle Devonian. Progressive closure of the PAO eventually provoked collision of this combined Altai-Mongolia-Chulyshman microcontinent with Siberia (Buslov et al., 2003). Several post Late Paleozoic reactivation pulses occurred and were predominantly controlled by the inherited Paleozoic structural architecture. Pre-existing zones of lithospheric weakness (e.g. suture zones) act as preferential deformation sites. Reactivation pulses were accompanied by mountain building and subsequent erosional denudation, causing basement cooling. Present-day reactivation in the Altai region is a distal effect of the continuous convergence between India and Eurasia (De Grave et al., 2007). The precursor of the current Chuya and Kurai basins formed in this tectonic framework during the Early Cenozoic as a transtensional basin (Delvaux et al., 1995).

The present study aims to constrain the aforementioned Paleozoic evolution of the Altai mountains by means of LA-ICP-MS zircon U/Pb dating (Fig. 2). An age of ~513 Ma dates the island arc magmatism in Gorny altai to the Middle Cambrian. A cluster of Middle to Late Devonian ages, ranging from ~394 Ma to ~36 4Ma is associated with a period of magmatism accompanying the Altai-Mongolia-Chulyshman collision. This study also revealed a Late Silurian (~420 Ma) age from a granitic intrustion in Altai-Mongolia and an Early Permian (~297 Ma) age from a small dioritic intrusion near the Kurai suture. Similar Late Silurian ages have been published for the Chinese Altai (e.g. Sun et al., 2008), northern Kazakhstan (e.g. Kröner et al., 2008) and the Junggar basin (Chen et al., 2010). Most authors related these ages to magmatism in the Boshchekul-Chingiz volcanic arc, which originated from the subduction of the PAO beneath Altai-Mongolia. Our data suggest that this magmatism occurs further North than previously thought. Further geochemical characterization is required to evaluate this hypothesis. Late Ordovician and Early Silurian ages have also been found by De Grave et al. (2009) in the Teletskoye graben North of the Chuya-Kurai zone and are related to a magmatic pulse due to the collision between Tuva-Mongolia and West-Sayan. Our age for the dioritic intrusion evidences a Permian magmatic episode that was hitherto unkown for the Russian Altai. This Early Permian age (~297 Ma) can be related to post-collisional magmatism accompanying the Kazakhstan-Siberia collision. (Briggs et al., 2007; Windley et al., 2007). This latter episode caused reactivation of the South Altai sutures as strike-slip fault zones (Buslov et al., 2003).

Apparent apatite fission track (AFT) and apatite (U-Th)/He (AHe) ages together with their thermal modelling evidence a polyphase Meso-Cenozoic thermal history. AFT ages range from ~114 Ma to ~72 Ma, whilst AHe-ages are younger and range from ~94 Ma to ~1.6 Ma (Fig. 2). A Late Mesozoic cooling event (~120-70 Ma) affected the Altai basement and is documented by all investigated samples. This cooling event emplaced the sampled rocks at temperatures of 50-80°C, corresponding to a depth of ~2-3 km in the upper crust when considering a geothermal gradient of 25 °C/km. This cooling was followed by a long period of thermotectonic stability for the samples in the area near the Kurai suture. However, samples from the northern slopes of South Chuya Range, which borders the Chuya basin to the South, indicate slow but gradual cooling throughout the Cenozoic. Recent reactivation, bringing the rocks to their present outcrop position, started in the Late Miocene (~8 Ma) for the entire region. Cooling

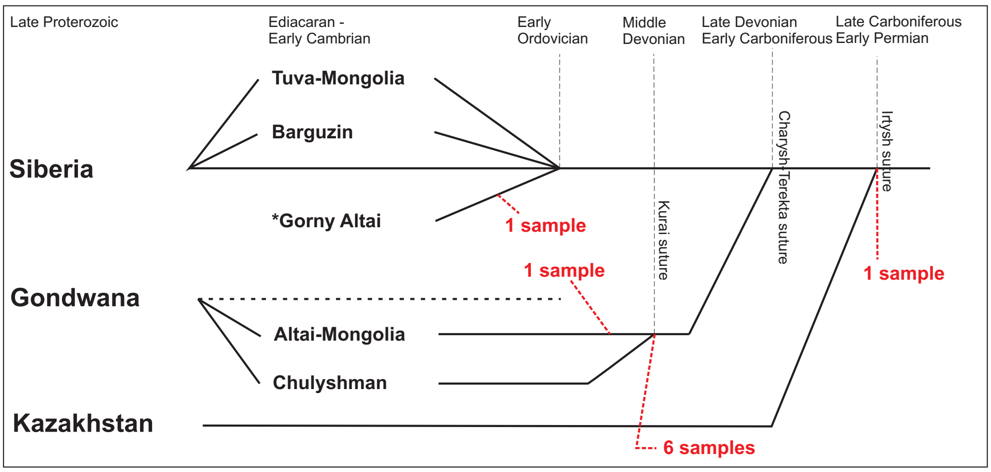

Figure 2. Terrane assembly diagram for the Southern Russian Altai, with indication of the U/Pb ages in the time-referenced general tectonic evolution model of the region. The asterisk indicates the genesis and build-up of the Gorny Altai terrane as a result of accretion processes. Discussion: see text.

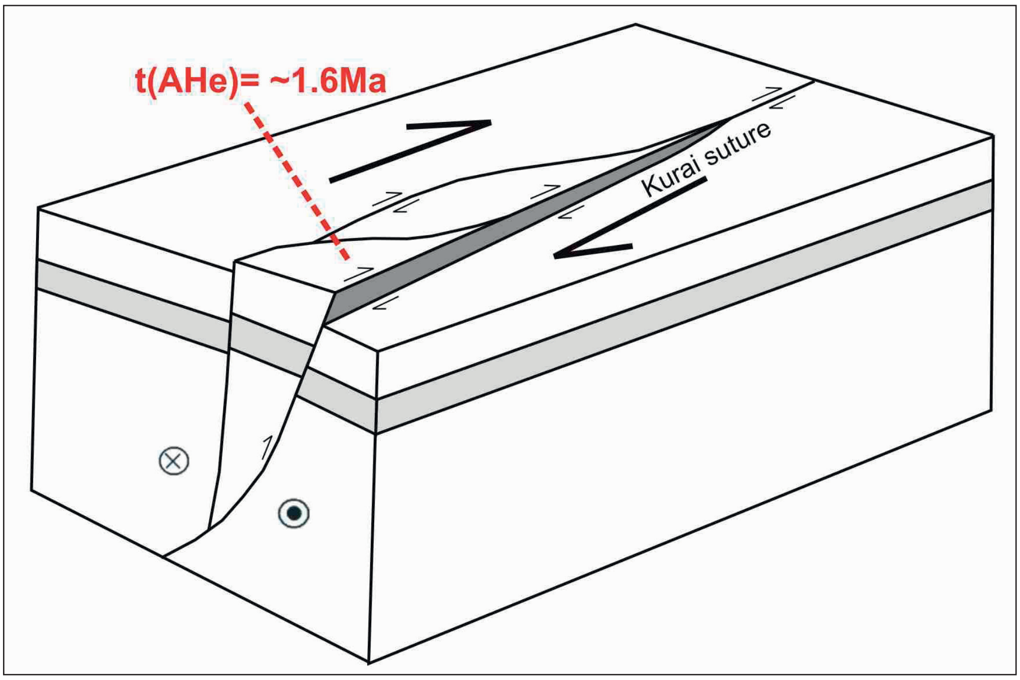

Figure 3. Tectonic block model for the sample with an AHe-age of ~1.6Ma. The sample is located in a sigma-shaped tectonic block, bordered by the Kurai fault zone to the south and by dextral strike-slip faults to the north. In a transpressive stress regime, such blocks may rapidly be squeezed out along the suture in positive flower structures.

clearly accelerated during the Pliocene for samples North of the Kurai suture. AHe-ages are Late Mesozoic or Cenozoic and confirm results from AFT thermochronology. One AHe-age of ~1.6 Ma was found for a sample located just North of the Kurai suture. Unfortunately, this sample did not contain sufficient high-quality apatite grains to allow AFT-dating. For one sample, the AFT age (~72 Ma) is younger with respect to the AHe age (~94 Ma). Anomalously high AHe ages constitute a well-known problem (Spiegel et al., 2009) and are often attributed to either excess ^{4}He produced by inclusions, to radiation damage and He-trapping (Shuster et al., 2006) or to ^{4}He implantation from adjacent U-rich minerals and rocks (Spiegel et al., 2009).

The Late Mesozoic cooling event can be linked to the closure of the Mongol-Okhotsk Ocean between Siberia and the Amur continent (North China – Mongolia). Subsequent continent-continent collision caused tectonic reactivation and denudation throughout the northern CAOB, followed by a period of thermal relaxation. Similar results have been described elsewhere in the Altai region (De Grave & Van den haute, 2002; De Grave et al, 2008; 2009; Jolivet et al., 2007; Vassallo et al., 2007). Samples located near the Kurai suture experienced a period of thermal stability during most of the Cenozoic, corresponding with an episode of relative tectonic stability throughout the region. Slow basement cooling of samples at northern slopes of the South Chuya Range, representing a slightly tilted Cretaceous peneplain, can be attributed to either large wavelength lithospheric buckling during the initial stages of the Himalayan orogeny (e.g. Cloetingh et al., 1999) or flexural effects at the onset of subsidence of the proto-Chuya-Kurai basin.

AFT modelling suggests that recent tectonic reactivation in the Chuya-Kurai zone started in the Late Miocene (~8 Ma), as also evidenced by coarser sedimentation in both basins at that time (Delvaux et al., 1995). Tthe discrepancy of the cooling histories of the samples on either side of the Kurai suture can be explained by thrust faulting along the reactivated suture. Thrusting initially was strongly dextral and oblique, but a re-arrangement of the local stress field with a σ_1-component more or less perpendicular to the Kurai suture caused accelerated denudation North of the fault zone from the mid-Miocene onwards. Simultaneously, the Charysh-Terekta suture was reactivated as a sinistral strike-slip fault zone (Delvaux et al., 1995; Buslov et al., 1999). In our tectonic model, the combined action of both fault zones caused the separation of the Chuya and Kurai basins along the rising Chagan-Uzun horst. The Kurai Block was extruded towards the West in an extensive stress field, as supported by Quaternary paleostress tensors obtained by Delvaux et al. (1995). In this mechanism of escape tectonics, the Kurai basin could rapidly subside, explaining the lower altitude of its basin floor relative to that of the current Chuya basin. One of our samples just North of the Kurai suture has an AHe-age of ~1.6 Ma. To our knowledge, this is the youngest absolute age published for the entire CAOB North of Tien Shan. Such a young age, corresponding to denudation rates of 1 to 1.5 km/Ma, can not solely be attributed to thrusting along the Kurai suture. The dioritic intrusion from which the sample was obtained is located in a series of small sigma-shaped tectonic blocks, bordered by the Kurai fault zone to the South and by dextral strike-slip faults to the North (Fig. 3). Such small blocks can potentially be squeezed out along the suture at high velocities in a system of positive flower structures in the regionally predominant transpressive stress field. In any case, this age forms the ultimate evidence of ongoing tectonic reactivation in the Chuya-Kurai zone.

Acknowledgements

We would like to thank M.M. Buslov and F. Zhimulev for assistance during fieldwork. We would also like to thank D. Stockli for performing the (U-Th)/He-analysis. SG is supported by the Institute for the Promotion of Innovation through Science and Technology in Flanders. JDG is supported by the FWO Fund for Scientific Research – Flanders. Dr. Damien Delvaux and an anonymous reviewer are acknowledged for their critical comments that undoubtedly contributed to this paper. We dedicate this paper to Aleksander "Sacha" Ryabinin for his good company and scientific input during many field expeditions over the last few years. Sacha unfortunately perished in an avalanche during fieldwork in January 2010, which was a fatal loss for all of us.

References

BRIGGS, S.M. et al., 2007. Late Paleozoic history of the Ertrix Fault in Chinese Altai and its implications for the development of the Central Asian Orogenic System. *Geological Society of America,* 119: 944-960.

BUSLOV, M.M. & WATANABE, T., 1996. Intrasubduction collision and its role in the evolution of an accretionary wedge: the Kurai zone of Gorny Altai (Central Asia). *Russian Geology and Geophysics,* 37: 74-84.

BUSLOV, M.M., ZYKIN, V.S., NOVIKOV, I.S. & DELVAUX, D., 1999. Cenozoic history of the Chuya depression (Gorny Altai): structure and geodynamics. *Russian Geology and Geophysics,* 40: 1687-1701.

BUSLOV, M.M. et al., 2001. Evolution of the Paleo-Asian Ocean (Altai-Sayan region, Central Asia) and collision of possible Gondwana-derived terranes with the southern marginal part of the Siberian continent. *Geosciences Journal,* 5: 203-224.

BUSLOV, M.M. et al., 2003. Role of strike-slip faulting in Late Paleozoic – Early Mesozoic tectonics and geodynamics of the Altai-Sayan and East Kazashstan Regions. *Russian Geology and Geophysics,* 44: 49-75.

CHEN, J.-F. et al., 2010. Zircon U–Pb ages and tectonic implications of Paleozoic plutons in northern West Junggar, North Xinjiang, China. *Lithos,* 115: 137-152.

CLOETINGH, S., BUROV, E. & POLIAKOV, A., 1999. Lithospheric folding: primary response to compression? (from central Asia to Paris basin). *Tectonics,* 18: 1064-1083.

DE GRAVE, J. & VAN DEN HAUTE, P., 2002. Denudation and cooling of the Lake Teletskoye Region in the Altai Mountains (South Siberia) as revealed by apatite fission-track thermochronology. *Tectonophysics,* 349: 145-159.

DE GRAVE, J., BUSLOV, M.M. & VAN DEN HAUTE, P., 2007. Distant effects of India-Eurasia convergence and Mesozoic intracontinental deformation in Central Asia: Constraints from apatite fission-track thermochronology. *Journal of Asian Earth Sciences,* 29: 188-204.

DE GRAVE, J., VAN DEN HAUTE, P., BUSLOV, M.M., DEHANDSCHUTTER, B. & GLORIE, S., 2008. Apatite fission-track thermochronology applied to the Chulyshman Plateau, Siberian Altai Region. *Radiation Measurements,* 43: 38-42.

DE GRAVE, J. et al., 2009. Multi-method chronometry of the Teletskoye graben and its basement, Siberian Altai Mountains: new insights on its thermo-tectonic evolution. From: Lisker, F., Ventura, B., Glasmacher, U.A. Thermochrolological methods: From paleotemperature Constraints to Landscape evolution models. *Geological Society, London, Special Publications,* 324: 237-259.

DELVAUX, D., THEUNISSEN, K., VAN DER MEER, R. & BERZIN, N., 1995. Dynamics and paleostress of the Cenozoic Kurai-Chuya depression of Gorny Altai (South Siberia): tectonic and climatic control. *Russian Geology and Geophysics,* 36: 26-45.

DOBRETSOV, N.L., BUSLOV, M.M., DELVAUX, D., BERZIN, N.A. & ERMIKOV V.D., 1996. Meso- and Cenozoic tectonics of the Central Asian mountain belt: effects of lithospheric plate interaction and mantle plumes. *International Geology Review,* 38: 430-466.

JOLIVET, M. et al., 2007. Mongolian summits: an uplifted, flat, old but still preserved erosion surface. *Geology,* 35: 871-874.

KRÖNER, A. et al., 2008. Palaeozoic arc magmatism in the Central Asian Orogenic Beld of Kazakhstan: SHRIMP zircon ages and whole-rock Nd isotopic systematics. *Journal of Asian Earth Sciences,* 32: 118-130.

SAFONOVA, I.Y., SIMONOV, V.A., BUSLOV, M.M., OTA, T. & MARUYAMA, S., 2008. Neoproterozoic basalts of the Paleo-Asian Ocean (Kurai accretionary zone, Gorny Altai, Russia): geochemistry, petrogenesis, and geodynamics. *Russian Geology and Geophysics,* 49: 254-271.

SHUSTER, D.L., FLOWERS, R.M., FARLEY, K.A., 2006. The influence of natural radiation damage on helium diffusion kinetics in apatite. *Earth and Planetary Science Letters* 249: 148–161.

SPIEGEL, C., KOHN, B., BELTON, D., BERNER, Z., GLEADOW, A., 2009. Apatite (U–Th–Sm)/He thermochronology of rapidly cooled samples: the effect of He implantation. *Earth and Planetary Science Letters* 285: 105–114.

SUN, M. et al., 2008. Zircon U–Pb and Hf isotopic study of gneissic rocks from the Chinese Altai: progressive accretionary history in the early to middle Paleozoic. *Chemical Geology,* 247: 352-383.

VASSALLO, R. et al., 2007. Uplift age and rates of the Gurvan Bogd system (Gobi-Altay) by apatite fission track analysis. *Earth and Planetary Science Letters,* 259: 333-346.

WINDLEY, B.F., ALEXEIEV, D., XIAO, W., KRÖNER, A. & BADARCH, G., 2007. Tectonic models for the accretion of the Central Asian Orogenic Belt. *Journal of the Geological Society of London,* 164: 31-47.

Manuscript received 05.05.2011, accepted in revised form 01.06.2011, available on line 15.06.2011